

HISTORY OF NEBULAR PROCESSING TRACED BY SILICATE STARDUST IN IDPS. S. Messenger¹, L. P. Keller², K. Nakamura-Messenger^{1,2}, A. Nguyen^{1,2} ¹Robert M. Walker Laboratory for Space Science, ARES, NASA JSC, 2101 NASA parkway, Houston TX 77573, USA ²ESCG, Johnson Space Center, Houston TX 77058. (scott.r.messenger@nasa.gov)

Introduction: Chondritic porous interplanetary dust particles (CP-IDPs) may be the best preserved remnants of primordial solar system materials, in part because they were not affected by parent body hydrothermal alteration. Their primitive characteristics include fine grained, unequilibrated, anhydrous mineralogy, enrichment in volatile elements, and abundant molecular cloud material and silicate stardust [1-4]. However, while the majority of CP-IDP materials likely derived from the Solar System, their formation processes and provenance are poorly constrained.

Stardust abundances provide a relative measure of the extent of processing that the Solar System starting materials has undergone in primitive materials. For example, among primitive meteorites silicate stardust abundances vary by over two orders of magnitude (<10 – 200 ppm) [5,6]. This range of abundances is ascribed to varying extents of aqueous processing in the meteorite parent bodies. The higher average silicate stardust abundances among CP-IDPs (>375 ppm; [7]) are thus attributable to the lack of aqueous processing of these materials. Yet, silicate stardust abundances in IDPs also vary considerably. While the silicate stardust abundance in IDPs having anomalous N isotopic compositions was reported to be 375 ppm, the abundance in IDPs lacking N anomalies is < 10 ppm [7]. Furthermore, these values are significantly eclipsed among some IDPs with abundances ranging from 2,000 ppm to 10,000 ppm [4,5,8]. Given that CP-IDPs have not been significantly affected by parent body processes, the difference in silicate stardust abundances among these IDPs must reflect varying extents of nebular processing.

Here we present recent results of a systematic coordinated mineralogical/isotopic study of large cluster IDPs aimed at (1) characterizing the mineralogy of presolar silicates and (2) delineating the mineralogical and petrographic characteristics of IDPs with differing silicate stardust abundances. One of the goals of this study is to better understand the earliest stages of evolution of the Solar System starting materials.

Experimental: The IDP studied here (AA4) is a 15 μm fragment of a very large IDP L2036 cluster #4 which is known to have high abundances of silicate stardust (~2,000 ppm) [9]. Fragments of this cluster IDP display a wide range in compositions, from almost pure carbonaceous material (>90%) to more classic

CP-IDP mineralogy. In general, this cluster is particularly fine grained, with typical grain sizes <0.5 μm .

The particle was embedded in elemental S for ultramicrotomy and sliced into 70 nm sections that were deposited onto C-coated TEM grids. Some sections were placed onto Cu grid bars for isotopic measurements, while most sections were reserved for TEM characterization prior to isotopic measurements. This approach enables parallel efforts for isotopic mapping to establish silicate stardust abundances as well as systematic coordinated mineralogical mapping by TEM followed by isotopic analysis. Quantitative X-ray maps, bright-field, and dark-field images were obtained from the thin sections using a JEOL 2500SE field-emission STEM.

Isotopic measurements were performed with the JSC NanoSIMS 50L ion microprobe. O and N isotopic images were taken simultaneously, acquiring images of $^{16}\text{O}^-$, $^{17}\text{O}^-$, $^{18}\text{O}^-$, $^{12}\text{C}^{14}\text{N}^-$, $^{12}\text{C}^{15}\text{N}^-$, $^{28}\text{Si}^-$, and $^{24}\text{Mg}^{16}\text{O}^-$ in multidetection with electron multipliers. The images were obtained by rastering a 0.1–0.2 pA, <100 nm Cs^+ beam over 10 – 15 μm fields of view. The images were repeatedly acquired for a total of 20 – 30 image layers for each analysis. The duration of each analysis ranged from 8–20 hours. Sample charging was minimized with the use of an electron flood gun. 10 μm grains of San Carlos olivine and 1-hydroxy benzotriazole hydrate placed near each sample served as external isotopic standards for O and N, respectively.

Results & Discussion: TEM investigation of AA4 showed it to be fine grained (<0.5 μm) and dominated by an assemblage of polycrystalline grains, or equilibrated aggregates (EAs). Other phases observed include rare GEMS (glass with embedded metal and sulfide) grains, forsterite, and an enstatite platelet. Carbonaceous material is rare. Minor magnetite rims are observed on some grains in the section, indicating moderate atmospheric entry heating.

Twelve microtome sections of AA4 were subjected to O and N isotopic imaging, and four of these sections were previously mineralogically mapped by TEM. A total of five presolar silicate grains were identified among these sections, yielding an estimated abundance of 1,600 ppm. The isotopic compositions of the presolar silicate grains fall within the range of presolar oxides and silicates [4–7,10], with three having large ^{17}O -enrichments and normal $^{18}\text{O}/^{16}\text{O}$ ratios (Group 1

grains) and two grain having pronounced enrichments in both ^{17}O and ^{18}O (Group 4 grains).

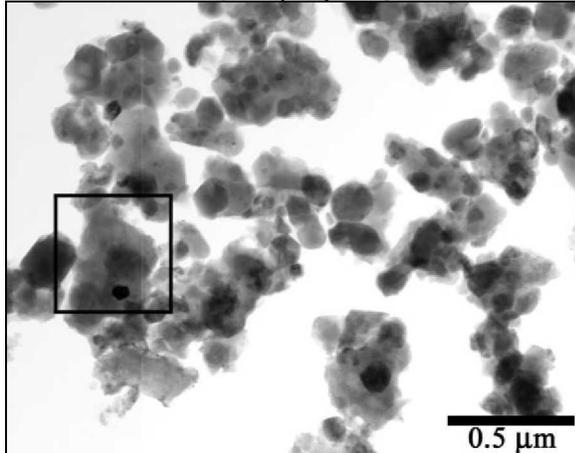


Figure 1: Brightfield TEM image of a section of AA4 containing a presolar silicate-dominated EA grain (boxed) that is associated with numerous equilibrated aggregates.

Two of the presolar grains were identified in sections previously mapped by TEM, and both grains are equilibrated aggregates (Figures 1 & 2). The bulk composition of the first presolar EA (Fig. 1) has $\text{Mg/Si} = 0.9$, $\text{Fe/Si} = 0.4$, $\text{S/Si} = 0.24$ (at. ratios) with minor Al, Ca and Ni. The second presolar EA (Fig. 2) is slightly more Mg-rich with $\text{Mg/Si} = 1.1$, $\text{Fe/Si} = 0.24$, $\text{S/Si} = 0.16$ and higher Ca and Al compared with the previous grain. Chemical maps of the second grain indicate the Ca,Al-rich region is a probable diopside grain.

The fact that the two presolar equilibrated aggregates are found within an IDP fragment having an unusually high abundance of EAs suggests that all of these grains experienced a thermal annealing process. The setting of this annealing event was most likely in the solar nebula; it is unlikely to have resulted from atmospheric entry heating owing to the presence of intact GEMS grains and the minor development of magnetite. Furthermore, other fragments of the parent cluster IDP also do not appear to be strongly heated and have low abundances of EAs. Although the nature of the precursors of the presolar EAs cannot be established with certainty, the bulk compositions of both presolar EA grains fall within the (wide) range of GEMS grains [11].

Equilibrated aggregates are commonly observed in IDPs as 0.1- 2 μm -sized, irregularly shaped, polycrystalline objects. Their abundance varies among IDPs from a few vol. % to nearly the entire IDP mass [12]. EAs have simple mineralogy dominated by Mg-rich crystalline silicates (enstatite and forsterite), pyrrhotite, Mg-Al, Si-rich mesostasis, and minor diopside. While the mineralogy and morphologies of EAs show they were never molten, their textures are consistent with

formation by subsolidus annealing of amorphous precursors.

Spectroscopic observations of young stellar systems reveal a progressive change in the composition of dust from predominantly amorphous silicates (presumed to be interstellar grains) into crystalline grains [13,14]. The details of the transformation mechanism and the subsequent transport of the crystalline grains from the hot inner part of the disk to cooler regions are poorly constrained.

Owing to their formation in cold, distant region of the solar nebula it was proposed that cometary olivine grains formed by annealing of interstellar amorphous silicates, rather than condensation from a high temperature gas [15]. It is interesting to note that the two presolar EAs identified here are polymineralic assemblages that do not contain olivine and have also likely undergone a phase transformation while preserving their isotopic identity. Additional coordinated mineralogical studies of IDPs with differing silicate stardust abundances may reveal further details about the nebular evolution of the Solar System starting materials.

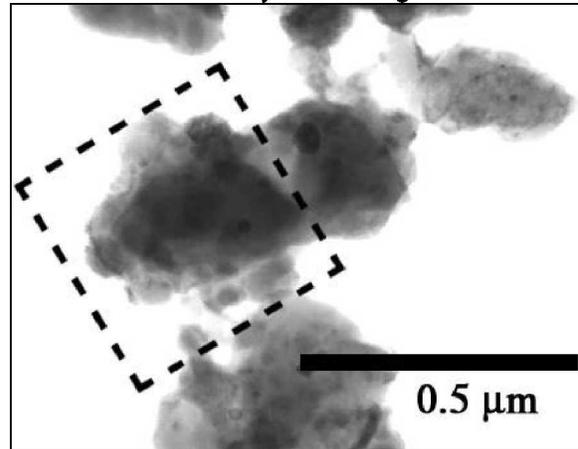


Figure 2: Brightfield TEM image of a presolar equilibrated aggregate (boxed).

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